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ENGINEERING DESIGN FILE

Project/Task	Engineering Support of OU 7-13/14 Feasibility Study
Subtask	Plasma Arc Furnace Data

TITLE: Index and Discussion of Data Gathered for the Plasma Arc Centrifugal Furnace

SUMMARY: In support of the OU 7-13/14 feasibility study, information is being gathered on various processes and technologies. This EDF contains information for the plasma arc centrifugal furnace, including:

1. A brief summary of plasma arc testing relevant to OU 7-13/14 remediation
2. A preliminary review of the plasma arc furnace relative to CERCLA feasibility study evaluation critieria and questions
3. A discussion of issues
4. A list of references.
5. An estimate of the number of furnaces needed remediation of OU 7-13/14.

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Plasma Arc Furnace Demonstration and Operating Experience

Brief summaries of demonstration testing and operating experience of plasma arc centrifugal furnaces are given below. The summaries are not meant to be exhaustive, as additional detail can be obtained from the references.

1. **Pit 9 LPT Tests** - The original Pit 9 schedule called for the LPT tests to be performed August 15 to September 18, 1996, LPT test reports prepared August 29 to December 16, 1996. The proposed delayed schedule for Pit 9 calls has the LPT tests beginning in June, 1997. Unless the OU 7-13/14 feasibility schedule is also delayed, the LPT test data will be received too late to benefit the feasibility study.

2. **Pit 9 Test Bed Tests** - Scheduled to be performed in mid-1996.

3. **Pit 9 POP tests** (See References 1, 11, 12, 18, 19, 20, 21, 22, 25, 38, 40)

Pit 9 Proof of Principle (POP) tests included the Pu Volatilization Test, the Maintenance in Containment test and a 100-Hour Operations Test.

Four tests were run in a lab-scale rotating hearth furnace to better determine volatilization of plutonium during plasma treatment. Tests were performed with soil spiked with cerium; soil spiked with plutonium; soil, iron and PVC spiked with cerium; and soil, iron and PVC spiked with plutonium. The amount of Cl in the PVC was about equal to the amount of Ce and about 66 times the amount of Pu. After each run, samples were taken throughout the system to determine cerium and plutonium mass balances. Mass balance closure varied from 100 to 128% in the four tests. Distribution of cerium and plutonium was concluded to be:

	Test 1 Ce (no Cl)	Test 2 Ce (w/ Cl)	Test 3 Pu (no Cl)	Test 4 Pu (w/ Cl)
Slag	99.8%	99.6%	99.9%	99.6%
Hearth and Ram	0.2%	0.36%	0.02%	0.36%
Condensed w/in furnace	0.008%	0.026%	0.01%	<0.01%
Off-gas system	0.012%	0.018%	0.01%	<0.01%
HEPA filter	0.020%	0.046%	0.02%	0.03%

The Maintenance in Containment test was designed to demonstrate key maintenance activities could be accomplished in proven containment systems. Using full-scale equipment, maintenance in containment was demonstrated for maintenance of the plasma torch and for replacing the centrifuge bearing.

The 100-hr test was performed using the PACT-6 system at the Component Development and Integration Facility in Butte. Feeds to the furnace during the test includes a high organic feed of 80.1% soil, 8.9% steel, 8% organics and 3% calcium silicate; a high nitrate feed of 78.29% soil, 8.71% steel, 10% nitrate, 1.52% cement, and 1.48% water; a "reliability" feed of 90.8% soil, 5% steel, and 4.2% organics; and a simulated Pit 9 feed containing 73.76% soil, 10% steel, 4.99% organics, 1.25% cerium oxide, and 10% simulated Rocky Flats sludges.

The PACT system was operated for 100.09 hours within a 160.1-hour window, for an availability of 63%. The majority of the downtime encountered during the test was because of electrode failures. Overfilling of slag barrels, plugging the secondary combustion chamber (SCC), plugging the off-gas system, a feeder chute falling into the primary chamber melt, and an electrical power outage also contributed to down time.

The slag was subjected to TCLP analysis and no detectable RCRA-hazardous metals were detected, with the detection limit for most metals being a tenth of the LDR limit. The slag also met INEL TRU Waste Acceptance Criteria. Mass balances were performed for cerium and chlorine. Ninety-eight percent of the cerium was found in the slag pours, skull (slag remaining in chamber), or primary chamber bottom below throat, and 2% in the scrubber water system. The scrubber water contained 96.245% of the chlorine.

Most of the problems encountered in the 100-hour test were not unexpected. The following solutions were proposed for the Pit 9 furnace:

1. Water leaks in the ram leakage: The problem is inherent with the PACT-6 system at the CDIF because of the acute angle between the ram and the slag and because of the short standoff distance between the torch and the molten slag. The Pit 9 furnace will be the larger PACT-8 system which has a different ram orientation and a greater standoff distance.

2. Slag overfilling: Several options will be investigated during design.

3. Electrode failures: Electrodes failed because the water supply pressure and flow was marginal for the torch and because a fabrication error resulted in an improper fit of the electrode with the torch water baffle. Based on operating experience of a PACT-8 system in Switzerland, the electrode is expected to be 3-5 times longer in the PACT-8 system than in a PACT-6 system.

4. SCC plugging: The PACT-6 system uses an SCC beneath the primary chamber, which gives rise to a slag buildup on the pour path, the SCC walls. On the PACT-8 system, the SCC is not beneath but adjacent to the primary chamber, with the offgas takeoff line relocated out of the molten slag path.

5. Feeder chute: The PACT-8 system will not contain a feeder chute.

6. Off-gas plugging: Plugging of the off-gas system was attributed to vaporized sodium condensing on the first cold surface encountered, the exit flange of the SCC. Various design changes to avoid or control the location of condensation will be evaluated.

7. Loss of hydraulic power - An electrical power outage resulted in loss of hydraulic power, which in turn caused a catastrophic slag pour. Two options will be evaluated for Pit 9 to mitigate the effects of hydraulic power loss. These options are the use of a large safety mold and the use of a water cooled plug.

4. **RWMC soil and BWID tests** (References 5, 13, 15, 34, 35)

The RWMC soil and Buried Waste Integrated Demonstration (BWID) plasma arc tests were performed at the CDIF facility from August 1992 to January, 1994. Three test series were performed, one to obtain a detailed cerium mass balance, one series testing simulated Rocky Flats and other sludges, and one aimed at reducing NO_x emissions.

In the cerium test series, an initial run was made to minimize the interference of skull residue on the mass balance. Then three runs of 8-11 hours each were made using a feed of 60.25% INEL soil, 18% wood, 15% carbon steel, 3% stainless steel, 1.25% cerium oxide, 1% Pb, 1% Al, and 0.5% trichloroethane. Three methods were used to calculate cerium recovery in the skull, and gave cumulative recoveries of 66-120%. Less than 0.1% of the cerium was found elsewhere in the system.

The sludge series consisted of runs of the following feed compositions:

Sludge-1: (Series 743) 89% soil, 8% organics, 3% Ca silicate
Sludge-2: (Series 745) 87.6% soil, 10% nitrates, 1.24% cement, 1.14% water
Sludge-3: 70% soil, 10% sulfates, 17.5% sand, 2.5% water
Sludge-4: 70% soil, 10% sulfates, 17.5% clay, 2.5% water

A number of tests were aborted due to torch operability problems, numerous problems were experienced in moving the torch off the copper throat assembly, and resulted in arc instability, secondary arcing, and eventually torch cooling water leaks. After correcting torch air flow problem, 4 runs were made, lasting 5-10 hours each. Extensive slag leachability analyses and characterization using SEM/EDX techniques were performed after these tests. Additional studies were recommended to better understand how various sludge compositions affect slag durability.

The objective of the NO_x Reduction Series was to investigate the effects on NO_x emissions of removing nitrogen or oxygen. A torch configuration to support operation using an Ar-O_2 mixture could not be identified. The tests indicate that NO_x is formed whenever N_2 and O_2 are present in the primary chamber and in contact with the electric arc. NO_x emissions were not reduced sufficiently to eliminate the need for an NO_x control system.

5. **PACT-8 Systems Operation** (References 6, 7, 15, 60)

A PACT-8 system was installed in Switzerland for Moser Glaser and Co. (MGC) in 1990 and permitted in May, 1991. Difficulties with the initial feeder design resulted in a redesign.[6] The unit treats chemical plant waste. RETECH designed two other PACT-8 systems for European customers, one in conjunction with a soil washing process for military waste, the other at a radioactive waste site.[6, 15] This system will feed drums of organic liquids, combustible solids and metal waste.

Feed for the PACT-8 System for treatment of low-level radioactive waste will consist of 200-L drums and be remotely unloaded. The furnace can be fed in 3 ways, by a horizontal drum feeder, pumped liquids, or a port for heavy metal parts. Off-gases are prequenched with air or water to 1100°C, cooled to 450°C by heat exchange, and then quenched to 70°C, scrubbed, passed through a HEPA filter, heated to 300°C, and passed through an NO_x reactor.[7] Offgases are analyzed for HCl, SO_2, NO_x, CO, CO_2, O_2, and dust prior to release from the stack.[7]

A safety analysis was performed for quench tank failure, a drum burning in the entrance hall, enhanced thermal destruction in the furnace, a power failure, a break-down of offgas piping, an earthquake, and an airplane crash. Almost all processes are either automated or remotely controlled to minimize radiation exposure to personnel to negligible quantities.[7]

6. **SITE Tests** (References 15, 17, 41, 50, 59)

Between October 1989 and June 1991, about 30 shakedown tests of a PACT-6 system were performed in Ukiah, California. Modifications were made before shipping the unit to the CDIF in Butte for SITE tests, which were performed in July, 1991. Three identical tests were performed using soil from the Silver Bow Creek Superfund Site with 10 wt% No. 2 diesel fuel, 2.8% ZnO, and 1000 ppm hexachlorobenzene added.

Destruction removal efficiencies were found to be >99.9968% to >99.99991 for hexachlorobenzene, >99.9872 to 99.99965 for 2-methylnaphthalene, and >99.993% for xylenes. Total hydrocarbons in the stack amounted to <4 ppm and CO was 1.4 ppm. NO_x emissions were high, 4800 ppm, corrected to 7% O_2. Particulate emissions (0.24-0.42 grains/dscf) exceeded the RCRA limit of 0.08 grains/dscf in each of the 3 tests. The slag was shown to be nonleachable and the scrubber liquid contained no organics.

The furnace required 3-5 hrs to reach primary/secondary chamber temperatures. Mass balances were not attempted since a portion of material remains in the furnace after each test. The torch power was 410 kW to 460 kW, the average chamber temperature, 2250°F and afterburner temperature 1800°F. The scrubber was not effective in capturing volatile metals. A large portion of the zinc in the soil feed plated out in the blower and exhaust gas duct.

The cost for a system processing 2200 lb/hr of contaminated soil with a 70% on-line factor was estimated to be $757/ton; and for a 500 lb/hr system $1816/ton.[41]

Equipment failures resulted in frequent stoppage and maintenance. During the first test a scrubber sump pump overheated and tripped the system. Particulate built up in the exhaust blower in the first two tests, and caused a shutdown of the second test. During the third test, a torch cooling water leak resulted in a 3-hour delay.

The energy consumption in the tests was approximately 8 kWh/lb of soil, high compared to the theoretical energy to melt soil, which is approximately 0.3 kWh/lb.

7. **Energetic Materials Tests** (References 13, 39, 53, 58)

Initial evaluation of plasma arc technology for use in demilitarization involved the testing of 20 different small caliber and hand-held pyrotechnic, smoke and dye items. Test objectives including the demonstration of safely feeding the devices into the system and to characterize the performance of the system for treatment of these energetic materials, including slag characterization and DRE of contained organics.

The safety tests demonstrated that the selected devices could be processed without generating unacceptable primary chamber overpressures. DREs for hexachloroethane and different dyes were shown to be greater than 99.99%. The slag passed EPA TCLP leachability requirements.

Equipment upgrades at the Butte facility are planned to support the ARDEC FY95/FY96 Plasma Demilitarization program. These include offgas system modifications to reduce particulate carryover, addition of a nontransferred arc torch, installation of an ordnance feeder, and modification of the torch control to an automated system. Duration testing will be the test focus, in order to assess and improve reliability and maintainability and gain data for scale-up to a full-scale unit. Testing is planned to be completed in 1996.

8. **Minimum Additive Waste Stabilization (MAWS)** (References 5, 36)

Objectives of the MAWS test program were to demonstrate processing of high-metal content materials and to demonstrate the capability to predict slag durability. Fifteen tests were performed with a bench-scale unit (1.5 foot diameter tub) using INEL soils mixed with 10-70% metals and 1% CeO_2. One test included 3% $FeCl_3$ in the feed to determine the effect of Cl on metals volatilization, and lead at a concentration of 2% was added in one test.

Only five tests achieved full oxidation of the feed metal. Failure to oxidize metals was not dependent on the feed metal concentration, but the apparent cause was a lack of sufficient oxygen penetrating into the melt. Reducing the feed mass by half and changing the O_2 lance position resulted in the successful runs.

Slag analysis showed that PACT treatment of high-metal content feeds can produce a final waste form equal to or better than existing standard high-level waste glasses. The slags produced contained both crystalline and vitreous phases and may be formulated such that both phases are very durable. It was concluded from the tests that the Argonne model provided a useful correlation between slag composition and chemical durability.

9. **Bench-Scale Low Level Radioactive Waste** (References 10, 16)

A PACT-1.5 system was used to test surrogate nuclear power plant solid waste. The primary objectives of the tests were to confirm organic destruction, determine if a metal phase will form separately from the slag phase, and confirm the leach resistance of the slag. Twelve tests were conducted using feeds of differing amounts of metal (carbon steel and stainless steel pipe), concrete, glass, plastic and PVC.

In the first test, it was confirmed that direct impingement of an oxygen jet on the bath would oxidize the metal. Oxygen jet parameters and operating conditions were changed for the other runs in order to recover a metal phase.

Additional tests were performed to determine the behavior of cesium and cobalt. Typically, 88% of the cobalt was found in the metal phase, 12% in the slag, and 0.04% in the offgas. The material balance for cesium was not good, significant amounts of cesium were suspected to be deposited in the off-gas pipe. The slag contained 53% of the cesium, 1% was found in the metal, 9% in the offgas, and 37% unaccounted for.

PRELIMINARY EVALUATION OF THE PLASMA ARC CENTRIFUGAL FURNACE BASED ON CERCLA DETAILED EVALUATION CRITERIA AND QUESTIONS

Questions from the EPA guidance document for performing detailed evaluations of alternatives in feasibility studies are listed below. Because the questions are for alternative remediation systems rather than technologies, some questions do not apply to the plasma arc centrifugal furnace technology, although they were reviewed because the plasma arc will be a major component in the representative retrieval/ex-situ treatment alternative. Answers are given based on data collected for the plasma arc centrifugal furnace. Additional information needed or expected for specific questions is noted.

Basis and assumptions:

1. The plasma arc furnace will treat waste, heavily contaminated soil, organic liquids from soil washing, and concentrated TRU from leach process. See Attachment for different estimates of waste that will be treated.
2. Slag from the plasma melter will be disposed of at WIPP.
3. Estimated date of start of remediation is 2000, and extends for 15 years.

1. Overall Protection of Human Health and the Environment

    1.1 Are risks (through each pathway) reduced to acceptable levels, eliminated or controlled?

        Risks are reduced by removal of waste and soil, processing waste into a vitrified form and disposal at WIPP

    1.2 Are short-term risks acceptable?

        The plasma furnace successfully achieved POP-test performance objectives demonstrating remote maintenance (Reference 18), and achieving an availability greater than 57% in the 100-hr operation test (Reference 21). However several questions were raised (Ref. 22) regarding the frequency of maintenance and hands-on operation during the 100-hr POP test. Most of these maintenance issues were expected in the 100-hr test because of limitations of the system used for the test (Reference 21). Design changes have been incorporated to improve remote operation and solve the problems experienced in the 100-hr test (References 12, 21, 47). Calculations of short-term risk levels for the retrieval/ex situ treatment alternative need to be performed. The LPT tests would provide additional data relevant to short-term risks, but may not be available in time for use in the FS evaluation.

        See also the discussion of safety under the Issues section.

2. Compliance with ARARs

    2.1 How does the alternative meet chemical-specific ARARs?

        Chemical specific ARARs include emission limits from the National Emission Standard for Hazardous Air Pollutants and the State of Idaho regulations, contaminant levels for liquid wastes from the Idaho Safe Drinking Act, and regulations regarding PCBs from the Toxic Substances Control Act (TSCA). No liquid effluent is expected. The TSCA-required destruction efficiency for PCBs is expected to be met based on the temperature and residence times in the primary chamber and secondary combustion chamber.

        Air emissions will be dependent on the off-gas cleanup system, which will be designed to meet all emission requirements. Based on 100-hr POP test, annual emissions of regulated constituents were calculated to be: (Reference 40)

NO_x	*9.36 T/yr*	*MT-ID ARAR:*	*40 T/yr*
Particulate	*0.016*		*25*
SO_2	*0.037*		*40*
CO	*0.075*		*100*

See also Reference 21, which contains additional (and different) estimates of emissions for full-scale remediation of SDA waste. Suppliers of the Pit 9 off-gas treatment equipment provide guarantees of removal efficiencies of HCl, SO_x, NO_x, and particulate.

2.2 How does the alternative meet location-specific ARARs?
2.3 How does the alternative meet action-specific ARARs?
2.4 How does the alternative meet other orders, criteria, advisories, guidance?

Evaluation of the plasma arc furnace in light of other ARARs and orders is more appropriate as part of the full retrieval/treatment system.

3. Long-term Effectiveness and Permanence

3.1 What is the magnitude of residual risks?

Based on the Pit 9 treatment system, the only material that could be returned to the SDA would be stabilized sludge from the offgas scrubber blowdown that has been treated sufficiently to meet TCLP requirements. Residual risks will be calculated for entire treatment system.

3.2 Are controls to manage residuals or untreated waste adequate and reliable?

Not applicable

4. Reduction of Toxicity, Mobility, or Volume Through Treatment

4.1 Treatment process and remedy

4.1.1 Does the treatment process employed address the principal threats?
(Principal threats = release of contaminants to groundwater or air)
Yes, threats are addressed via removal of contaminants, destruction of organic contaminants and immobilization through melting of the inorganic contaminants.

4.1.2 Are there any special requirements for the treatment process?
Relative to other thermal treatment processes, the plasma arc furnace is very flexible and robust (see Reference 13). Energy requirements for the process are relatively high.

4.2 Amount of hazardous material destroyed or treated

4.2.1 What portion (mass, volume) of contaminated material is destroyed?
A high percentage of the contaminated material will be destroyed by

chemical reaction or vitrification. The organic portion of the waste will be oxidized, most metals (involatile or semivolatile) will be oxidized, nitrates will be reduced, and inorganics will be vitrified into a relatively homogeneous slag. Reference 21 contains calculations of volume reduction for the 100-hr POP test and estimates for Pit 9 treatment. Because of the high soil loadings in the feed to the POP test, the volume reduction for the 100-hr test was only about 60% (slag volume compared to feed volume), estimates for the Pit 9 remediation are much higher. Assuming an average feed composition of 30% metal, 20% combustible, 40% inorganic and 10% water (including chemically bound), an average feed density of 40 lb/ft^3, a slag density of 180 lb/ft^3, and no recycle of secondary wastes to the furnace, the volume reduction would be 82%.

4.2.2 What portion (mass, volume) of contaminated material is treated? *The plasma furnace will treat all waste containing contamination above yet-to-be specified levels.*

4.3 To what extent are the effects of treatment irreversible?

Organic destruction and vitrification are irreversible and produce a highly durable waste form relative to all alternative waste forms.

4.4 Type and quantity of treatment residual

No waste will the plasma melter/offgas treatment will be returned to the pits and trenches unless it meets specified disposal criteria, which are expected to be at least as stringent as for waste retrieved but not treated. The major waste stream expected to be returned is expected to be solidified scrubber blowdown sludge. Data from the LPT tests is needed to better determine the amount and characteristics fo this waste.

4.5 Statutory preference for treatment as a principle element

4.5.1 Are principal threats within the scope of the action?

Yes

4.5.2 Is treatment used to reduce inherent hazard posed by principal threats?

Yes

5. Short-Term Effectiveness

5.1 Protection of community during remedial actions

5.1.1 What are the risks to the community during remedial actions that must be addressed?

The only risks to the community as a result of plasma treatment result from potential gaseous release of contaminants. This would require simultaneous failure of both the components designed to remove the contaminants from the offgas (HEPA filters, NO_x *reactor, etc.), and the containment building.*

5.1.2 How will the risks to the community be addressed and mitigated?
Risks will be mitigated by removal of contaminants in offgas treatment system and in containment design.

5.1.3 What risks remain to the community that cannot be readily controlled?
None

5.2 Protection of workers during remedial action
See comments regarding remote operation and maintenance.

5.2.1 What are the risks to the workers during remedial actions that must be addressed?
Risks to workers include exposure to radiation, hazardous chemical and high temperatures.

5.2.2 What risks remain to the workers that cannot be readily controlled?
None are apparent at this time; maintenance on contaminated equipment may be the highest risk activity.

5.2.3 How will the risks to the workers be addressed and mitigated?
The risks are mitigated by containment systems, control systems, physical barriers (remote operation, etc.) and procedural limitations. Safety analyses will define and address hazards.

5.3 Environmental impacts

5.3.1 What environmental impacts are expected with the construction and implementation of the alternative?
Estimates of gaseous release given in References 21 and 40.

5.3.2 What are the available mitigation measures to be used and what is their reliability to minimize potential impacts?
The offgas treatment system is designed to remove pollutants to under regulatory limits. The containment design is expected to be based on

credible accident scenarios (need to confirm this when PSAR is available).

5.3.3 What are the impacts that cannot be avoided should the alternative be implemented?
See estimates of gaseous release given in References 21 and 41. See also the projected waste summary for Pit 9.

5.4 Time until remedial response objectives are achieved

5.4.1 How long until protection against the threats being addressed by the specific action is achieved?
Based on the ROD becoming final in September of 1998 and the use of the Pit 9 plasma furnace as part of the treatment system for OU 7-13/14, it is reasonable to expect that treatment could begin by the year 2000. Based on the furnace treating 50% of the TRU waste and 20% of the low level waste, 62.5% furnace availability, 30% soil in furnace feed, and upgrading the offgas system to a rate of 2000 lb/hr, treatment would be complete in 11 years. If the offgas system was upgrade to 1500 lb/hr, 15 years would be required. See attachment for calculations of furnace rates.

5.4.2 How long until any remaining site threats will be addressed?
No additional threats will need to be addressed once treatment is complete and treatment system decommissioned/removed.

5.4.3 How long until remedial response objectives are achieved?
Remedial action objectives will be progressively reached as treatment is performed.

6. Implementability

6.1 Ability to construct and operate technology

6.1.1 What difficulties may be associated with construction (and operation)?
Because of experience constructing Retech's PACT-8 system in Switzerland and PACT-6 systems, no unusual difficulties are expected associated with construction. Construction of Pit 9 system will provide an additional baseline for construction success/difficulties.

6.1.2 What uncertainties are related to construction?
None apparent

6.2 Reliability of technology: What is the likelihood that technical problems will lead to schedule delays?
This will be ultimately be answered by remediation of Pit 9, and if delays occur,

solutions to delay causes will greatly reduce the likelihood of delays for OU 7-13/14 remediation. LPT testing will also provide data regarding reliability. The availability in the 100-hour POP test was 63%.

6.3 Ease of undertaking additional remedial action, if necessary

6.3.1 What likely future remedial actions may be anticipated?
Not applicable to the plasma arc technology, but will apply to the ex-situ treatment alternative.

6.3.2 How difficult would it be to implement the additional remedial actions, if required?
Not applicable to the plasma arc technology, but will apply to the ex-situ treatment alternative.

6.4 Monitoring considerations
(These questions relate to overall remediation alternative and will be addressed in later analysis)

6.5 Coordination with other agencies
(These questions relate to overall remediation alternative and will be addressed in later analysis)

6.6 Availability of treatment, storage, capacity, and disposal services
(These questions relate to overall remediation alternative and will be addressed in later analysis)

6.7 Availability of prospective technology

6.7.1 Are technologies under consideration generally available and sufficiently demonstrated for the specific application?
(See summary of demonstration tests and commercial operation)

6.7.2 Will technologies require further development before they can be applied full-scale to the type of waste at the site?
Probably not. It's likely that at most three PACT-8 units would be sufficient to remediate OU 7-13/14, and only one may be adequate (See attachment). One unit of this size has been operating in Switzerland. If development needs are discovered during Pit 9 remediation, they will be addressed at that time. (Capacity of PACT 8 = 1980 lb/hr,[56])

6.7.3 When should the technology be available for full-scale use?
Technology is presently available at full-scale, although the wide range of wastes of OU 7-13/14 may present additional challenges for the

technology.

6.7.4 Will more than one vendor be available to provide a competitive bid? *Retech will have a clear advantage because of Pit 9 experience. There are other vendors of melter technologies and even plasma furnaces, and some will have some experience with RWMC soils and/or simulated wastes, but none will have as much as Retech.*

7. Costs

Based on the SITE Demonstration, cost estimate for a 2200 lb/hr PACT system, 70% on-line = $757/ton (Ref. 17, 41) (this cost does not include cost of the building, and capital costs for the process have been annualized based on a 15-yr life). This breakdown of this cost is as follows:

Site Preparation costs	*$37/ton*
Equipment costs	*100*
Startup and fixed costs	*250*
Labor costs	*208*
Supplies	*20*
Consumables	*110*
Facility mod., repair, replacement	*32*
Total	*$757/ton*

Capital cost est. for PACT-8: $5 million (Reference 41, p. 20) (without offgas treatment)

Other Cost Estimates: $800-1200/ton for 1 ton/hr, multiple shifts (Ref. 13)
$600-1200/ton (Reference 23)

Most significant variables affecting costs (prioritized) (Reference 23)

1. *Water content of feed*
2. *Waste characteristics*
3. *Site preparation*
4. *Labor rates*
5. *Waste quantity*
6. *Utility/fuel rates*
7. *Amount of debris with waste*
8. *Characteristics of soil*

Relative costs for characterization, pretreatment, melting and disposal for the plasma arc furnace compared to a Joule-heated melter are given in Reference 54.

More definitive cost estimates will be prepared in later analyses.

PLASMA ARC CENTRIFUGAL FURNACE ISSUES AND QUESTIONS

1. **Flexibility for wide range of wastes:** Development of the plasma arc furnace for treatment of hazardous/radioactive waste has occurred rapidly over the last decade. Most large scale tests, including POP tests, the BWID tests and the SITE program, have been run with >70% soil. Small-scale tests have demonstrated the ability of the technology to process high metal content wastes (yet, the feed still contained at least 29% soil) and also simulated low level radioactive waste (that contained no soil). However, the complexity and diversity of the RWMC buried waste exceeds the range of testing to date. Provisions have been incorporated into the design to make the technology very robust for a very wide range of waste compositions, contaminants, types, phases and forms (see References 13 and 29). Testing to date largely substantiates the claim that the technology is very robust and results in a durable melt over a wide range of feed compositions. However, virtually no data is available for a PACT-8 or PACT-6 system for high metal content feeds (50% or greater), 100% RF sludge feeds, feeds with high chlorine or fluorine, phosphate-containing feeds or other feeds with very high sodium or calcium contents, such as cement. The test bed tests, LPT tests and Pit 9 operation will provide a more complete answer as to the flexibility of the plasma arc furnace for OU 7-13/14 wastes.

Modeling some of these worst case scenarios could provide data on the melt composition and an indication of its acceptability. Recent testing has attempted to establish limits for feed and melt compositions (Reference 42). Additional test data that cover some of the potential extremes of OU 7-13/14 waste would answer questions regarding potential operational problems or unacceptable slag. The melt pool does provide a degree of homogenization. Also, a minimum soil addition is planned for the Pit 9 melter. The primary issue here is one of availability and maintenance.

Because of the volatility of lead and mercury, Retech would prefer that lead bricks and bulk mercury be separated and not treated in the plasma arc furnace (Reference 49), although they can be processed by recycle of lead from the scrub system to the furnace and stabilization of mercury removed in the scrub system.

2. **Volatility of TRU and other radionuclides:** Tests have been run with Ce, Pu, Cs and Co, and some of the test feeds included inorganic or organic chlorides. Volatilities of Ce/Pu have been shown to be low, while Cs gave relatively high volatilities (9% in offgas plus a large percentage unaccounted for). These tests have used relatively low Cl concentrations or contained other metals that could also form chlorides and compete with the TRU elements for Cl.

While the evidence to date shows only at most a few tenths of a percent of Ce or Pu outside the primary chamber and slag pours, the tests to date have been mostly with Ce only. The final BWID testing report of the plasma arc furnace recommended a study to compare the volatility of Ce to Pu, U, Am, and any other radionuclide elements of interest expected to be in the waste. POP testing only considered Ce and Pu. Retech's response to a request for information for the OU 7-13/14 feasibility study also stated that additional treatability studies may be required to demonstrate radionuclide behavior (Reference 49, pages 2,8). The issue is the production of mixed waste as a result of both TRU radionuclides and RCRA-hazardous metals in off-gas system wastes.

3. **Maintenance over long-term operation**: Various equipment failures were experienced in the 100-hr POP test. Design changes have been incorporated into the Pit 9 system that address these components. On the Pit 9 PACT-8 system, the SCC will not be under the primary chamber but off to the side. Thus the pour path is shorter, reducing the chance of overfilling the slag receiving container. Also, the safety mold has a high capacity. With the reconfiguration of the SCC, the offgas takeoff line from the primary chamber is no longer in the path of the slag pour, eliminating the chance of plugging the SCC. The electrode life is expected to be much higher in the Pit 9 PACT-8 system than it was for the PACT-6 furnace used in the POP test, based on data from the MGC PACT-8 furnace in Switzerland. For the MGC furnace, Retech guaranteed an electrode life of 50 hours for the first 500 hours of operation, 100 hours for the first 1000 hours, and 200 hours thereafter.

4. **Minimum amount of soil and/or additives needed to achieve adequate melt composition:** See discussion of issue #1 above. Recent information from Retech indicates a minimum of 30% soil will be required (Reference 49, page 5).

5. **Expected release rates of tritium and C-14**: The inventory of tritium disposed in the SDA pits and trenches is 6.3 million that of Pit 9 and the C-14 inventory is 8.4 million times greater. Pit 9 soil profile data that will be obtained as part of LPT tests will provide additional data on the inventory of these radionuclides. Depending on this data and release limits, modifications may be required to the offgas system to capture and process $^{14}CO_2$ and/or tritiated water into acceptable waste forms.

6. **Buildup of radionuclide and hazardous metals if HEPAs and other offgas system wastes are recycled**: To avoid a secondary waste containing RCRA-hazardous metals and certain radionuclides, recycling of solids condensed and collected in the offgas system to the furnace is needed, and hence there will be a buildup of these materials in the furnace. Based on information from Retech (Reference 49, p. 8), the buildup of lead will be 1.7 to 2 times that in the fresh feed, and the buildup for silver, cadmium, selenium and cesium 2.5 times that of the fresh feed. The buildup of strontium, chromium, nickel and barium will be small, only 1.1-1.2 times that in the fresh feed.

7. **Amount and final form of scrubber wastes:** Data is needed to confirm that the proposed solidification system for the concentrated scrubber blowdown wastes results in a solid product that meets disposal criteria.

8. **Optimization of slag durability/cooling rate:** Data generated during the BWID test program showed that the formation of a crystalline phase improved slag durability. Since cooling rate affects the degree of crystallization, the BWID slag study recommended optimization of slag durability by control of slag cooling rate.

9. **Measurement of temperature in molten pool**: Another recommendation of the BWID slag study was the development of a method to measure molten slag temperature, because of the importance of the temperature in affecting other variables such as slag viscosity, melter feed rate, and formation of precipitated phases.

10. **Capacity, availability, life** - The BWID report (by MSE) assumes a 60% availability in their cost analysis and POP test demonstrated 62.5% availability (Reference 34). Kirk McKinley reported 80-90% availability is expected for the Pit 9 system (Reference 29), although information from Retech (Reference 49, page 6) estimates a 60-70% availability for a system operating on a 3 shift basis. The SITE demonstration report (Reference 17) based their economic analysis on cases of 50%, 60% and 70% availability. The availability could have a significant impact on cost. Based on a feed rate of 115 million pounds (see attachment, Case 2B), 24-hr/day, 5-days/week operation, 2000 lb/hr feed rate and 60% availability, 1 furnace could process the feed in 16 years. At 80% availability, only 12 years would be required, resulting in considerable operating cost savings. For reasons explained in the POP 100-hr report, the failures causing downtimes for the 100-hr test have solutions and hence the availability should improve, although at present there does not appear to be any data supporting availability much greater than 60-70%. The BWID report cost analysis assumes replacement of furnaces every 5 years. However, when asked about furnace life on January 10, 1996, Bob Parker of Retech said that PACT-8 life will be much longer. Bob said that the Pit 9 furnace is designed for a 15-yr life, and the life could be extended by more frequent and extensive maintenance. If needed the life could also be extended beyond 15 years by design changes.

11. **Safety** - An explosion occurred on February 1, 1996 in the feeder on the PACT-6 system at the Western Environmental Technology Office.[62] An investigation into the accident concluded the probable contributing factors included a control system failure, a control logic problem, and an inadequate hazards analysis.[62] While lessons learned from this accident will undoubtedly be incorporated into future designs, the fact that an explosion occurred in a test facility gives rise to a potential for a serious accident at a site such as OU 7-13/14, which would process feeds with minimal characterization.

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ESTIMATE OF NUMBER OF PLASMA FURNACES REQUIRED FOR REMEDIATION OF OU 7-13/14

BASIS

1. Pit 9 furnace capacity: Based on information from Kirk McKinley (EDF ER-WAG7-79, INEL-95/271), the capacity of the Pit 9 furnace is 1000 lb/hr, BUT is limited by the offgas system and could be doubled by upgrading the offgas system. This value of 2000 lb/hr for the capacity of a PACT-8 furnace is verified by published literature.

2. Pit 9 furnace availability: The availability in the 100-hr POP test was 62.5%. In the same EDF as referenced in #1, Kirt McKinley estimated the availability would be 80-90%, but I don't believe a sufficient basis has been established for this range. Thus I used 62.5%.

3. 15 year treatment schedule (murder board assumption)

CASE 1: Murder Board Treatment Volume of 33,840 ft^3

1. The murder board assumes 15.6% combustibles, 9.8% metals, and 74.6% sludges/soils retrieved from the SDA. Assuming this same composition goes to the furnace (this may not be a good assumption), and taking densities for combustibles, metals and sludge from Arenholt/Knight, WTD-91-027, Table 11 and for soil from Barnes, EDF ER-WAG7-80, INEL-95/274, and assuming soil/sludge is 50% soil/50% sludge, the available and required capacities are:

Available Pit 9 furnace capacity: 2000 lb/hr

Required furnace capacity:

Combustible:	33,840 x 35.3 x 0.156 x 18 = 3.35 million lb
Metal:	33,840 x 35.3 x 0.098 x 97 = 11.36 million lb
Soil/Sludge:	33,840 x 35.3 x 0.746 x 84 = 74.86 million lb
Total:	89.6 million lb

50 weeks x .625 availability x 7 days/wk x 24 hrs/day = 5250 hrs/yr
(Pit 9 uses a stream factor considerably lower than this because the furnace is so oversized)

89,600,000/(15 years x 5250) = 1140 lb/hr

Conclusion: The single Pit 9 plasma furnace is adequate. If an availability of 70% or greater can be achieved over the course of remediating Pit 9, the offgas system will not need to be upgraded.

CASE 2: VOLUMES CONSISTENT WITH FEASIBILTITY ASSUMPTIONS

TRU Waste Volume = 2.2 million ft^3 (EDF ED-WAG7-80)
LL Waste Volume = 4.6 million ft^3 (EDF ED-WAG7-80)
Required soil to furnace = 30% of total feed
Average Waste Density = 40 lb/ft^3 (EDF ED-WAG7-80)
Amount of wastes from chemical treatment processed by furnace negligible

CASE 2A - Minimum Throughput

50% TRU waste treated by furnace (This is consistent with Pit 9 assumptions)
No LL waste treated (No basis except that most COCs are TRU)

(2,200,000 x 0.5 x 40)/0.7 = 63 million lbs to furnace

63,000,000/(15 x 5250) = 800 lb/hr

Conclusion: Pit 9 furnace and offgas system are adequate.

CASE 2B - Higher Throughput

50% TRU waste treated by furnace plus 20% LL waste

(4,600,000 x 0.2 x 40)/0.7 + (2,200,000 x 0.5 x 40)/0.7 = 115 million lb

115,000,000/(15 x 5250) = 1460 lb/hr

Conclusion: Furnace is adequate but offgas system would need to be upgraded. (This case represents, given the data available, the most reasonable, and shows a rate about 28% higher than the murder board assumption.)

CASE 2C - Maximum Reasonable Throughput

100% TRU waste treated by furnace plus 20% LL waste

(4,600,000 x 0.2 x 40)/0.7 + (2,200,000 x 40)/0.7 = 178 million lb

178,000,000/(15 x 5250) = 2260 lb/hr

Conclusion: The single furnace of Pit 9 would be adequate only if an availability of greater than 70% can be achieved. The offgas system would need to be upgraded. There is no real basis at present to establish how much low level waste needs to be treated. If the 50% assumed for Pit 9 proves correct, then 43% of the low level waste could be treated at the throughput of Case 2C.

CASE 2D - 100% of TRU and 100% of LL WASTE

(4,600,000 x 40)/0.7 + (2,200,000 x 40)/0.7 = 389 million lb

389,000,000/(15 x 5250) = 4940 lb/hr

Conclusion: Three furnaces would be required to achieve this rate (or 2 if the availability was at least 77%).